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PERFORMANCE EVALUATION OF AN AFFORDABLE SOLAR DRYER FOR DRYING CROPS

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KEY WORDS

Solar dryer, Collection efficiency, System drying efficiency, Pick-up efficiency

ABSTRACT

A Solar tunnel dryer was constructed at the Department of Mechanical Engineering of University of Moratuwa. Dryer performance was evaluated with two chimneys, GI sheet and wooden frame covered with polyethylene. Evaluation parameters are collection efficiency, system drying efficiency, and pick-up efficiency. Chillies were used as drying material. It was found that the second chimney gives better performances.

NOMENCLATURE

A_c-Collector area [m^2]
Cp-Air specific heat [$Jkg^{-1}K^{-1}$]
h_{as} -Adiabatic saturation humidity of the air entering the dryer [$kgkg^{-1}$]
h_i -Absolute humidity of air entering the drying chamber [$kgkg^{-1}$]
I_{c}- Insolation on collector surface [Wm^{-2}]
I_{d}-Total insolation incident upon collector [kJm^{-2}]
T_{bi} -Temperature at inlet of drying bed [^0C]
T_{bm} -Temperature at centre of drying bed [^0C]
T_{bo}- Temperature at outlet of drying bed [^0C]
T_{ci} - Temperature at inlet of collector [^0C]
T_{co} -Temperature at outlet of collector [^0C]
t -Drying time [s]
V-Volumetric flow rate of air [m^3s^{-1}]
w-Moisture evaporater [kg]
ΔH-Latent heat of vaporization of water [$kJkg^{-1}$]
ΔT–Air temperature elevation [K]
ρ-Air density [kgm^{-3}]
η_c-Collection efficiency
η_d –System drying efficiency
η_p -Pick-up efficiency

INTRODUCTION

The preservation of surplus crops and foodstuffs can be regarded as one of the first and most important techniques of food processing (Senadeera et al., 2003). Among them, one of the most commonly used methods is drying (Menon and Mujumdar, 1987). Sun drying is the most widely practiced agricultural drying operation in the world. The term sun drying is used to denote the spreading of the commodity in the sun on a suitable surface, hanging it from eaves of buildings and trees, or as in the case of cereal crops, drying on the stalk by standing in stooks or bundles. The direct exposure to sunlight, or more precisely ultra-violet radiation, can greatly reduced the level of nutrients such as vitamins in the dried product. Ever increasing, labour costs, improving quality standards and some times uncertain climates lead to construction of artificial dryers. These dryers are capable of providing a high quality product independent of the weather and with a low labour requirement. They are not, however, intrinsically suitable for the small-scale farmer or for the majority of agro-industries in developing countries. One of the common methods suitable for the farms of developing countries is Solar drying.

Solar drying relies, as does sun drying, on the sun as its source of energy. Solar drying differs from sun drying. In that a structure, often of very simple construction, is used to enhance the effect of the insolation. Compared to sun drying, solar dryers can generate higher air temperatures and consequential lower relative humidities, which are, both conducive to improved drying rates and lower final moisture content of the drying crops (Muhlbauer, 1986). This method has several advantages such as less spoilage and less microbiological infestation, thus leads to improved and more consistent product quality. Solar drying can also be a feasible alternative to those natural convection dryers that use wood or agricultural waste products as fuel. The saving of wood would probably be the main attraction of solar dryers. One of the common solar dryer is solar tunnel dryer. This becomes popular due to considerable reduction of drying time and significant improvement of product quality (Chou et al., 1997). Solar tunnel dryers have been used to dry fruits, vegetables, root crops, medicinal parts and fish (Gauhar, 1998).

A passive solar tunnel dryer was designed and constructed at the Department of Mechanical Engineering, University of Moratuwa, Sri-Lanka. The tunnel dryer was tested for its performance using two chimneys, sheet metal and Polyethylene respectively.

MATERIALS AND METHODS

Construction of the Solar Tunnel Dryer
The Solar tunnel dryer was designed to dry commodities under hot and humid weather conditions prevailing in North-Central Province of Sri Lanka where most of the agricultural products need drying (FIGURE 1).

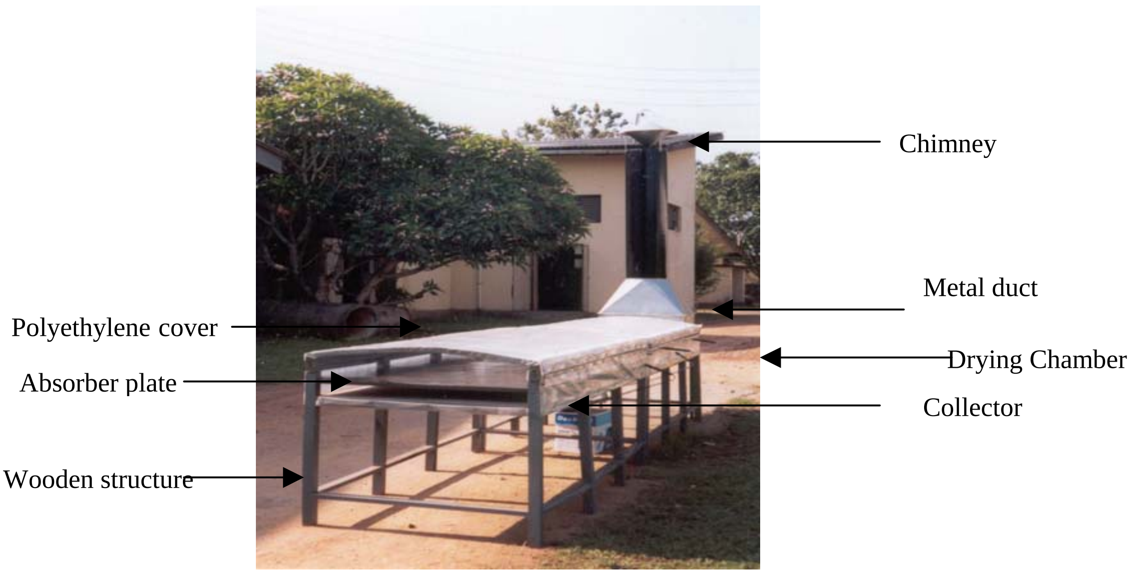

FIGURE 1. Solar Tunnel Dryer

The dryer consists of four separate parts, collector, drying chamber, metal duct and chimney to achieve the passive airflow. The collector and drying chamber are wooden structured and covered with UV-stabilized polyethylene, which is available at the local market. The top surfaces of the collector and drying chamber are designed in curved shape in order to increase the area of irradiance. They are made to open and close easily for the functions of spreading the drying commodity at the beginning of the day and cleaning the absorber plate and polyethylene cover. Base of the tunnel is covered with Rigifoam insulation of one inch, thickness in order to reduce the heat loss.

It was positioned in North-South direction so that, radiation from the sun was not disturbed by the chimney. Each of the collector and drying chamber has a width of 3 ft. and a length of 6 ft. The collector serves as a solar air heater. It is parallel pass type i.e. it allows airflow through both top and bottom of the absorber plate, which has an area of 3×6 ft.^{2} [Galvanized Iron sheet-gauge 22]. The absorber plate is painted black, a good absorber as well as a good emitter for radiation. The total height of the air column through the tunnel is 8 inches.

In the drying chamber, a wire mesh is used as the drying bed on which the commodity is spread and it is fixed at a higher level (nearly 1 inch.) than the absorber plate to allow a smooth flow for the heated air. The length of the drying bed (wire mesh) is 5½ ft. Other ½ ft. of the drying chamber is occupied by, the flow-controlling unit. The flow-controlling unit is positioned in between the collector and the drying chamber and it consists of two metal flaps in order to control the airflow through top and bottom of the drying chamber. These flaps can operate independently from outside by two levers.

The dryer is designed to ventilate by passive ventilation mechanism instead of forced convection. It was achieved by the use of metal duct and the chimney. The duct is the transition part between the drying chamber and the chimney, which allows a smooth airflow. Two chimneys were designed to compare their effectiveness upon the performance of the dryer. Chimney 1 (diameter 1ft, height 4ft, made out of GI sheet gauge 30) is made by rolling a thin sheet to form a cylinder and inside as well as outside of the cylinder is painted black while chimney 2 (diameter 1ft, height 4ft) is of wooden frame covered with Polyethylene (to form a cylinder) in order to provide green house effect. At the centre of chimney 2, two black painted rectangular metal plates, hitched cross wise, are placed in order to increase the effect of absorption of radiation.

Solar Irradiation Measurement
Total solar irradiation was measured using a Pyranometer (Model L1-250 Light meter) The solar radiation inside the collector was measured at intervals of 15 minutes.

Temperature Measurement
The temperatures at different points of collector and drying chamber were measured with thermocouples (K, J, T and E – types) Via a data logger (12 channels), every five minutes. In order to measure the temperatures at different points of air columns through top and bottom of the drying bed, temperature sensors were set at inlet and outlet of the collector as well as inlet, mid and outlet positions of the drying chamber as shown in FIGURE 3. The average temperature of the top and bottom air columns was taken as the temperature at the particular point of the tunnel.

Airflow rate Measurement
To obtain the airflow rate along the tunnel, velocity of the exit air through chimney was measured using a Velometer. The probe of the Velometer was set at the center of the chimney, 1/3 height from the bottom in order to measure the velocity of exit air. Readings were taken at 15 minute intervals.

RH Measurement
Two Relative humidity meters were placed at bed - inlet and outlet in order to obtain the difference of moisture content of airflow across the drying bed. Readings were taken at 15 minutes intervals. To find the relative humidity of atmospheric air, a wet and dry bulb thermometer was used.

Weight Measurement (of drying commodity)
To find the moisture removal rate weight measurements of 100g samples of the drying commodity (chillies) were taken using a physical balance with accuracy up to ten milligrams. Readings were taken at intervals of 60 minutes. A mechanical balance was used to measure the weight of the total batch and the readings were obtained at the beginning and end of each day.

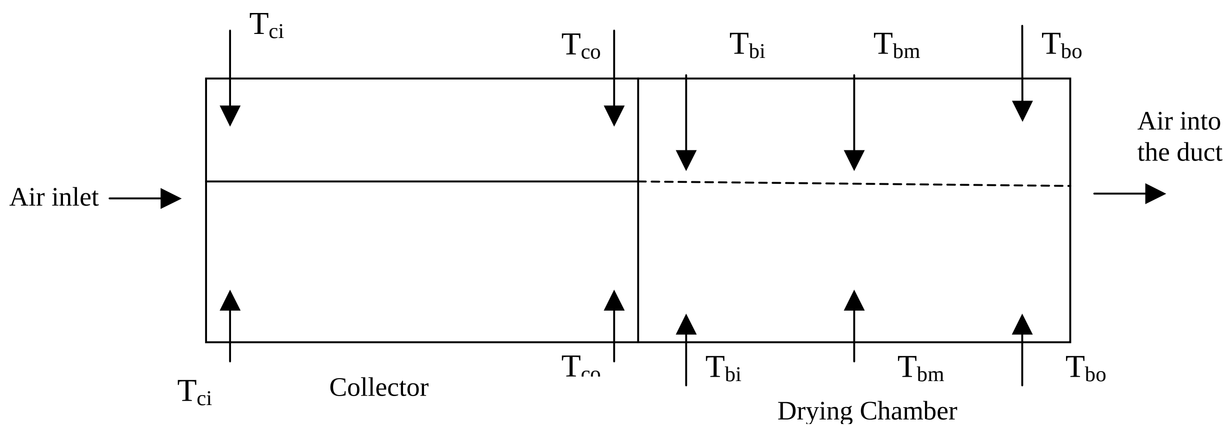

FIGURE 2. Positions of thermocouples along the tunnel (front elevation)

No Load and Load Test
Performance of the dryer was evaluated with no-load and load under several operating conditions. The main purpose of the no load test was to find the radiation collection capability of the collector and compare the values for η_c for the two chimneys when no commodity was on the drying bed. The purpose of the load test was to compare the rate of drying, by controlling the airflow through the drying chamber. The drying commodity was raw chillies. The experiments were carried out under following conditions; with no constraint to airflow (flow through top and bottom of the drying bed) with chimney 1 (batch size 7.0 kg) and by constraining air flow through bottom of the drying bed with chimney 1(batch size 7.0 kg). The amount of chillies in the dryer required about three days to dry to the necessary extent. So, pre-drying was an essential function, ie. the beginning of the

day, the collector plate and both sides of the Polyethylene cover were wiped out in order to remove the water vapor and dust particles due to condensation at night. Then the dryer was kept for sometime to vaporize any condensed water inside the collector and bed. After the pre-drying, the chillies were spread on the drying bed, forming a thin layer, to avoid compact packing. To find the rate of moisture removal rate, a 100g sample of the same commodity was dried separately in the dryer under same conditions and weight measurements was taken every one hour interval.

RESULTS AND DISCUSSION

NO LOAD TEST

Analysis for Temperature Variation Through the Tunnel

For no load, the radiation inside the collector and temperatures at collector inlet and outlet were measured and their variation with time of the day was plotted. To compare the effects of two chimneys, the temperature ratio of $(T_{co}-T_{ci})/(T_{bo}-T_{ci})$ was plotted against the time for chimney 1 and 2, both in FIGURE 3.

It is obvious that with chimney 2 above temperature ratio is increased; means the temperature of air at the outlet of the drying bed is comparatively low. It implies a higher air-flow through the drying bed in the case of chimney 2.

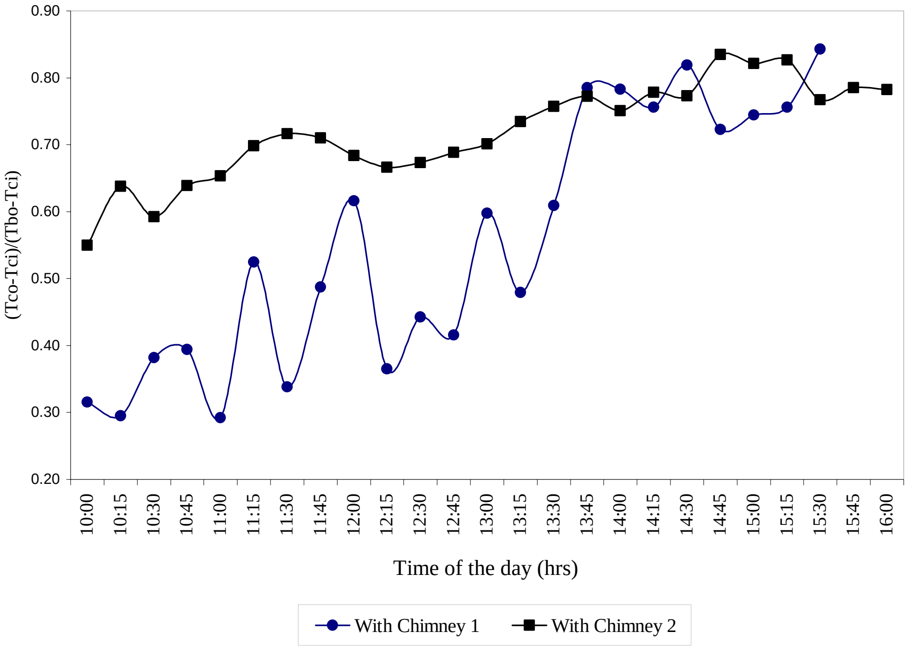

FIGURE 3 Variation of temp. ratio of (Collect:out-Collect:in) to (Bed:out-Collect:in) with time

Collection Efficiency (η_c)

Collection efficiency is defined as the ratio of heat received by the drying air to the insolation upon the absorber surface and is calculated from the equation 1.

$$\eta_c = V \times \rho \times \Delta T \times C_p / A_c \times I_c \qquad (1)$$

where, V= Volumetric flow rate of air (m^3s^{-1}), ρ = Air density (kgm^{-3}), ΔT = Air temperature elevation (K)
C_p= Air specific heat ($Jkg^{-1}K^{-1}$), A_c= Collector area (m^2), I_c = Insolation on collector surface (Wm^{-2})

Since η_c is a means of assessing of the performance of the collector, it was calculated using the readings of no load tests.

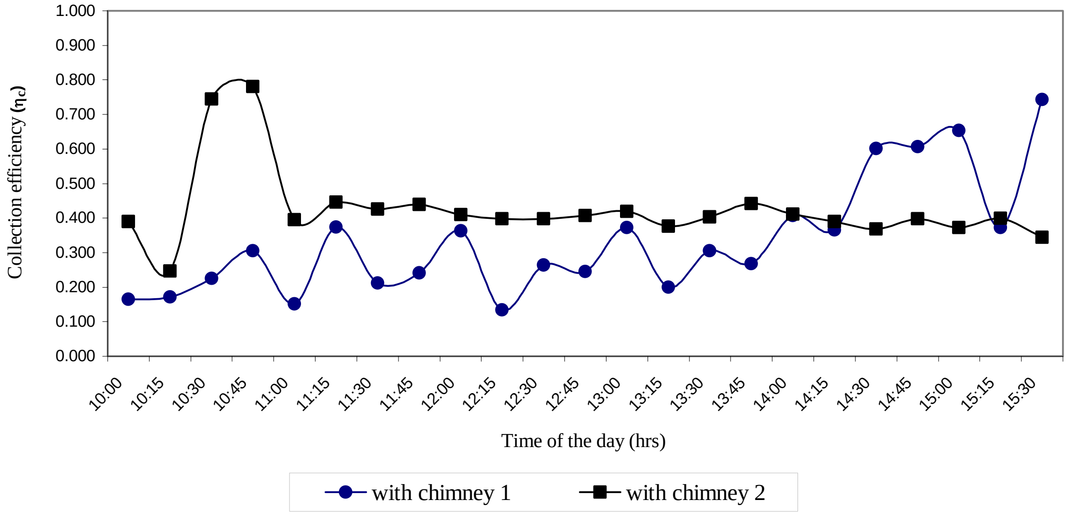

FIGURE 4 Variation of Collection efficiency with time

Figure 4 shows that the collection efficiency of the dryer with chimney 2 is greater than that with chimney 1. The mean radiation throughout the day for the cases with chimney 1 and 2 are 623.6 Wm^{-2} and 718.24 Wm^{-2} respectively. The overall Collection efficiency for chimney 1 was found to be 64 %, while for chimney 2, 68 %.

LOAD TESTS

The initial moisture content in matured raw Chillies was found to be 78% ~ 80 % (wb), through laboratory tests. According to the SLS 853 (Sri Lanka Standard Institution, 1989) the maximum moisture content that can exist in dried Chillies (Grade 1 type) should 10 % (wb). In our project, the moisture contents of dried Chillies were in-between 5 % and 6 % (wb). It can be observed that the fastest removal of moisture occurs when the airflow through the dryer is controlled (i.e. when bottom flap is closed).

System drying Efficiency (η_d)

This parameter is defined as the ratio of the energy required to evaporate the moisture to the energy supplied to the dryer. For solar calculations the heat supplied to the dryer is the insolation upon the collector. The system drying efficiency is calculated from the Equation 2.

$$\eta_d = w \times \Delta H_L / I_d \times A_c \qquad (2)$$

where,w = moisture evaporated (kg), ΔH_L = latent heat of vaporization of water, 2320 ($kJkg^{-1}$),
I_d = total hourly insolation upon collector, A_c = area of collector (m^2)

The overall value for system drying efficiencies, were 11 % (With both flaps opened), and 16% (Top flap opened; bottom flap closed).

Pick-up Efficiency (η_p)

This parameter is more useful for evaluating the actual evaporation of moisture from the commodity inside the solar dryer. The pick-up efficiency is defined as the ratio of moisture ‘ picked up ‘ by the air in the drying chamber to the theoretical capacity of the air to absorb moisture. The pick-up efficiency can also be calculated from the Equation 3.

$$\eta_p = w \ / V \times \rho \times t \times (h_{as} - h_i) \qquad (3)$$

where, w = moisture evaporated (kg), V = air flow rate (m^3s^{-1}), ρ = air density (kgm^{-3}), t = drying time (s),
h_i = absolute humidity of air entering the drying chamber, h_{as} = adiabatic saturation humidity of the air

The overall Pick-up efficiencies are, 13 % (with both flaps opened) and 20 % (flap opened; bottom flap closed).

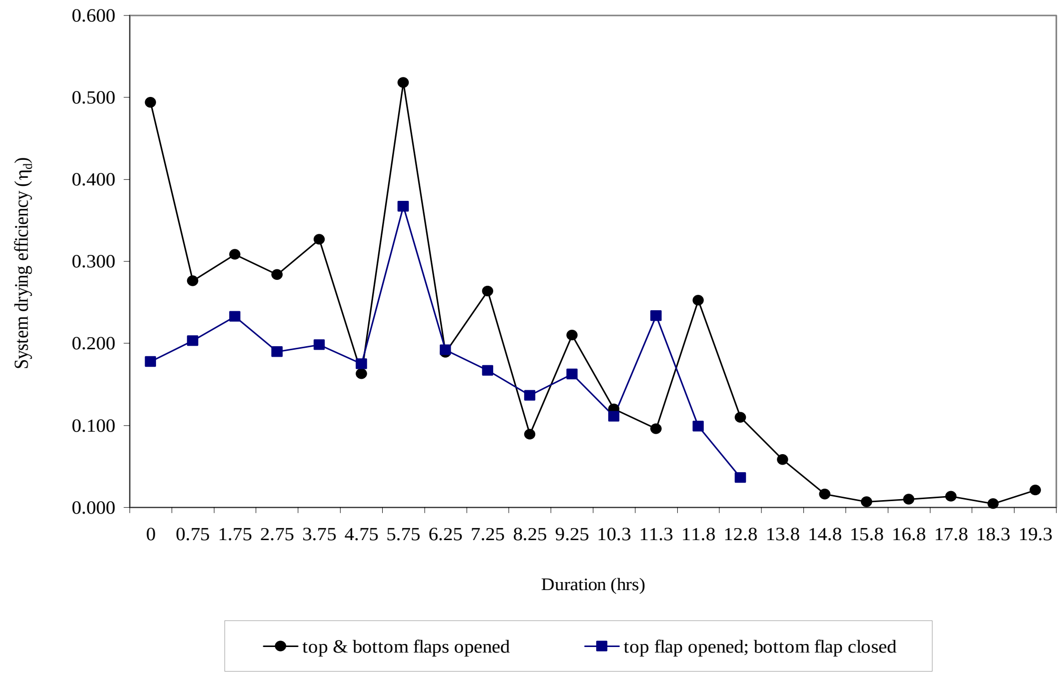

FIGURE 5 Variation of System drying efficiency with time

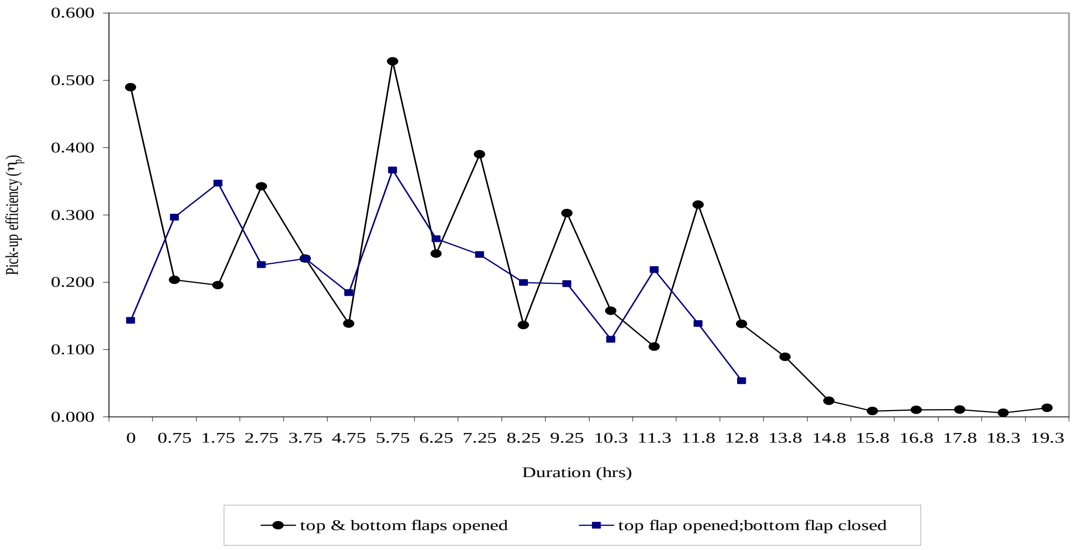

FIGURE 6 Variation of Pick-up efficiency with time

CONCLUSION

This dryer is suitable to dry small quantities of material (up to 15 kg) at household or farm level. Chimney with wooden frame and polyethylene cover gave higher efficiencies. Solar drying achieves higher drying rates compared with sun drying. Cost is comparatively small

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